ROYAL MILITARY COLLEGE OF CANADA

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

EEE455/7 ELECTRICAL AND COMPUTER ENGINEERING DESIGN PROJECT

DID-04 – Preliminary Design Specification

Presented by:

OCdt Carter Green

NCdt Royce Burningham

Presented to:

Dr. J Bray

Maj. J Lloyd

Nov 21, 2019

Table of Contents

1 Introduction

1.1 Variable Definitions

$$d - distance\ between\ readings$$

$$A_L - Arc\ length$$

$$r - radius\ of\ wheels$$

$$\theta - Angular\ Resolution\ of\ stepper\ motors$$

$$\Delta R - Downrange\ resolution$$

$$B_R - RF\ Bandwidth$$

$$\Delta CR - Crossrange\ resolution$$

$$\theta_{3dB} - 3dB\ Beamwidth$$

$$c - speed\ of\ light$$

$$\lambda - wavelength$$

1.2 Document purpose

The purpose of this document is to provide a more technical and in-depth explanation of the SAR imaging project, the motivation for the project, and an initial schedule for the project.

1.3 Background

The need for surveillance and intelligence collecting in a military context led defence researchers into the study of remote sensing. A subfield of remote sensing which aligned with already having airborne radar systems was synthetic aperture radar (SAR) imaging. SAR combines radar hardware, motion, and signal processing to produce an image like an optical photograph [1]. Whereas an optical image will capture light reflected from objects to produce an image, SAR imaging creates and sends out electromagnetic waves and captures their return to create a radar image. Normally cameras do not create their own light source and thus rely on external illumination or a flash to illuminate a target in order to photograph it. Shiny objects will reflect more light than others and will dominate the returns in the image leading to a loss of information. The radar returns will be dominated by objects that reflect electromagnetic energy such as buildings, vehicles, and other objects made of metal like rifles [1].

There are multiple benefits to using a SAR image compared to an optical image. The largest is that images can be generated at night and in any weather conditions because the radar transmits its own electromagnetic signal that penetrates atmospheric conditions. Another benefit is that man-made features dominate radar returns due to the materials that they are constructed of and their geometry. Using a low center frequency, it is possible to penetrate foliage and even the ground [1].

Nowadays optical images are simple to take and produce with digital cameras. Optical images can be taken and viewed almost instantaneously with a digital camera. In comparison, SAR images are much more complex to produce. SAR images require coherent integration and dwells need to be taken at precise intervals in space. The requirements just mentioned are only the hardware requirements. The radar must be in motion and the image must be rendered with signal processing techniques which can take minutes to produce the final image. Human interpretation of a radar image is more difficult as well. Because humans rely on optical imaging for sight, the content of photographs can be interpreted easily. The radar image may look like the optical image, but one could not infer at what time of day the image was taken and under what weather conditions meaning that there is a loss of information. Optical images will also be taken in colour which is preferable for comprehension of the image whereas a radar image will be monochrome because SAR only measures contrast [2].

Typical SAR imaging platforms are used in applications such as on aircraft or satellites and use a pulsed radar [1]. The motivation of this project is to create a side looking ground-based SAR imaging platform using a frequency modulated continuous wave (FMCW) radar. The platform will be an all-in-one platform that will handle movement, radar, and radar signal processing. This will show a proof-of-concept that SAR imaging can be applied to a ground-based scenario and will explore the use of FMCW SAR imaging.

The SAR imaging technique that will be implemented in the platform will be stripmap SAR along a single axis. A visual explanation for an airborne platform can be seen in figure 1. The platform will move along a straight line with the radar perpendicular to the direction of motion. While moving the radar will take measurements at equal spacing [1]. After all the data is collected the image formation algorithm is applied and will return a SAR image. If the image is out of focus an auto-focus algorithm can also be applied to the image to compensate for motion drift while collecting data.

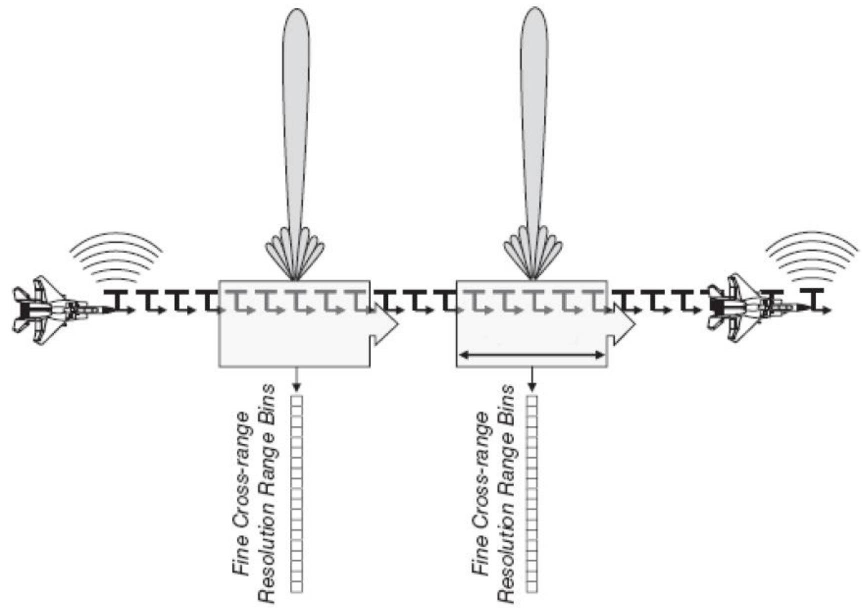


Figure 1 – Visual Explanation of Stripmap SAR Imaging [2]

2 Design Sections

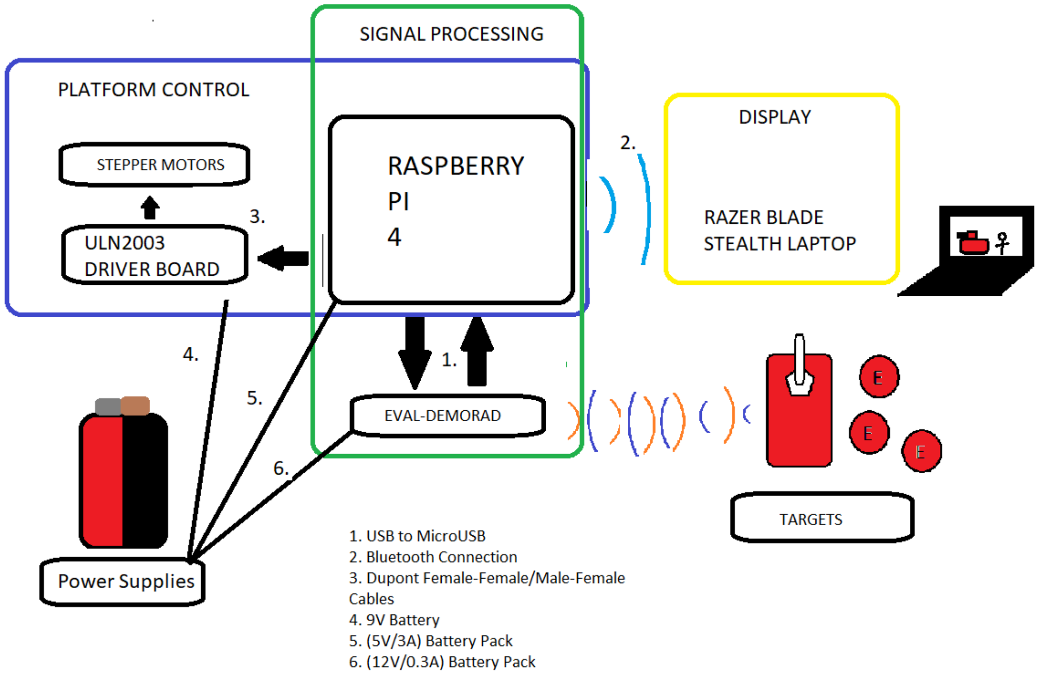


Figure 2 – System Overview Schematic

2.1 Design Overview

The SAR imaging system is broken down into three subsystems, platform control, signal processing, and the display of information. The Raspberry Pi 4 will be the centrepiece of the entire design where from a Python script it shall be able to handle all the motor control, processing of the data, and the sending of the image to the displays.

2.2 User Interface

Description

The user interface will allow a user to begin the imaging process as well as choose the distance that the platform travels. Through a graphical user interface (GUI) simple commands and choices will be selected by the user and sent to the Raspberry Pi for execution. This inclusion of the user will allow the user the ability to control some of the imaging parameters as well as simulate the scenario of imaging done by a faraway controller.

Interfacing

A Bluetooth connection between the Raspberry Pi and an external laptop will be made in order to begin the sequence. The choices of how far the platform travels, and when to start will be sent to the Raspberry Pi through the Bluetooth connection to the Raspberry Pi's terminal.

2.3 Platform Control

Description

This section of the project deals with the movement and of the platform along a single axis. Due to the nature of SAR images, in order to synthesize an image, the platform must move to simulate an array. The Raspberry Pi will control four separate stepper motors and have them rotate by a small distance to allow the Demorad to take a reading. The drive module for the stepper motors will be controlled through the Raspberry Pi's GPIO pins and will allow the Raspberry Pi to control the platform's movement. The Raspberry Pi and motors are responsible to ensure that the motors move by the same amount each time and move the required distance overall. All of this will be handled by a premade Python script running the motors.

Theory

The reason for which the incremental displacement of the platform is so important is that the radar is producing a virtual array. Just like an array if the distance is greater than $\frac{\lambda}{2}$, grating lobes will begin to occur [3]. As a result, a restriction was placed on the distance that the platform could move [1].

$$d < \frac{\lambda}{2\theta_{3dB}} \tag{2.1}$$

Where d represented the horizontal displacement, the radar could move in-between each reading, λ represented the wavelength for the radar, and θ_{3dB} was the three dB beamwidth which is a given characteristic of the radar. The calculation for the amount that the platform could move between each reading was determined via the universal wave equation which displays the relationship between the speed of light (c), the wavelength (λ) and the frequency (f) [4].

$$c = \lambda f \tag{2.2}$$

Knowing the frequency of the radar (f = 24GHz) and the speed of light ($c = 3x10^8 m/s$) the wavelength was able to be determined and from there the minimum displacement needed for the platform was determined [5]. With this value determined and knowing the angular resolution that the motors provided, 5.625degs, [6] the radius of the wheels could be calculated with the arc length formula [7].

$$A_L = r\theta \tag{2.3}$$

This derivation of the radius of the wheels was used in the equipment design and ensured that the platform's minimum movement was not greater than $\frac{\lambda}{2}$ in order to ensure grating lobes did not distort the image.

Interfacing

Battery to Stepper Motors

The stepper motors require a constant 5V DC in order to be powered and operate effectively [6]. During testing the Raspberry Pi's ability to power all four of the stepper motors off its own 5V pins was determined to be inadequate. As a result, a breadboard shall be added onto the platform which will have batteries powering it. This will ensure all the motors are receiving the right amount of voltage and current in order to rotate at the same time.

Raspberry Pi to Stepper Motors

The Raspberry Pi will be connected to the drive module through the female to female DuPont cables that came with the stepper motors, and the drive module will connect to the motors with the pre-attached five-pin cable. This will handle the transferring of commands from the Raspberry Pi's GPIO pins to the motors.

Battery to Raspberry Pi

The Raspberry Pi will be connected to an external battery supply as a power supply mounted on the platform. The power supply will be running a constant 5V/3A supply required for the Raspberry Pi 4 [8]. This will be fed from the battery pack to the Raspberry Pi using a USB Type C – Type C cable.

2.4 Signal Processing

Description

This section of the project deals with the acquisition of the data from the Demorad and the formation of the image by the Raspberry Pi. The platform will move the radar incrementally along the single axis and the radar will read the values at each point. The values read will then be sent to the Raspberry Pi for storing and processing. This will work cyclically from the same Python script which controls the stepper motors where the Raspberry Pi will move the platform, ask the Demorad for values, read the values, and store them for processing. This will happen along the given horizontal displacement until the complete image is formed.

Theory

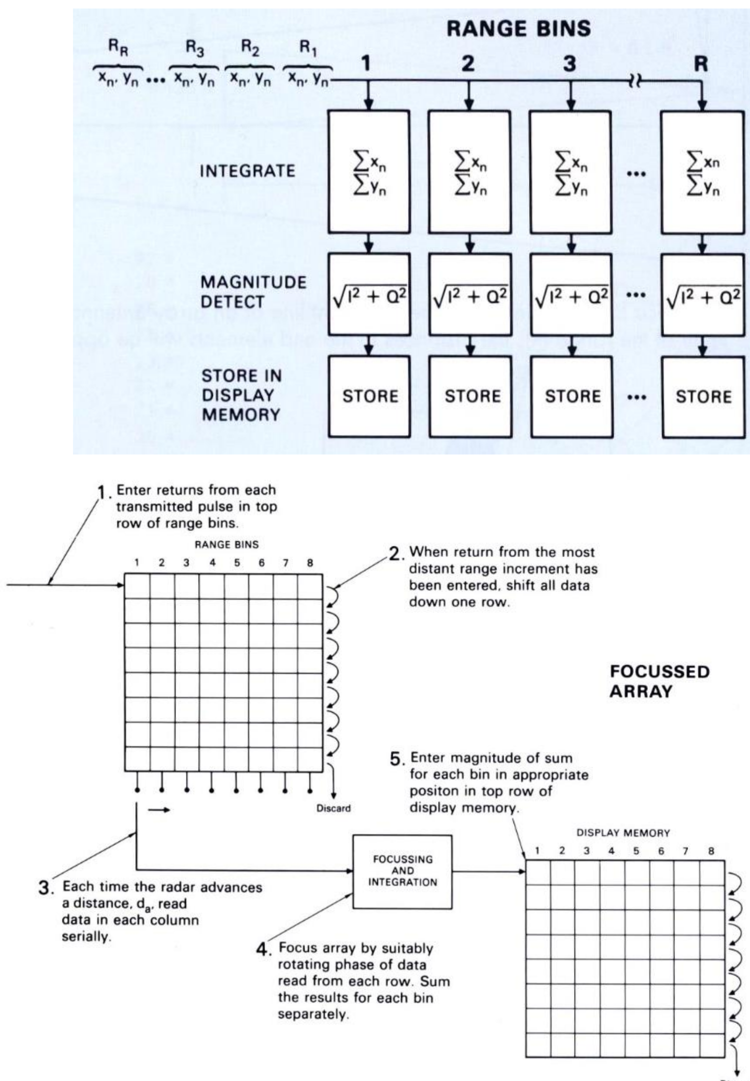


Figure 3 – SAR Imaging Algorithm Explanation [9]

The algorithm to develop the SAR image will start by having the platform begin at a starting point, d_0, and with the Demorad facing perpendicular to the direction of motion. The FMCW of the Demorad will create a set number of range bins that extend from the radar to the far wall in a distance known as downrange. Due to the fast accumulation of range bins perpendicular to the direction of the platform, this is called fast time, whereas the accumulation of range bins in the parallel direction of the platform is known as slow time. As the Demorad sits at this starting point, the information from the Demorad is sent to the Raspberry Pi which is applying the fast Fourier transform (FFT) in order to obtain the I and Q values of each downrange bin. These values of I and Q are held on the Raspberry Pi for later processing. After the accumulation of the row of values from the starting point, the platform will then be moved to the second point, d_1, whose distance from point d_0 was determined by (2.1). The process of obtaining the row of I and Q values is then repeated at point d_1 and the platform is again moved along to the next point. Each time the radar reaches a new location it is generating a new row of downrange bins and bin contains I and Q values which are sent to the Raspberry Pi. After the platform has reached a certain point along its axis, d_n, the radar has obtained enough values in order to generate the first row of downrange pixels for the image. The radar forms this row of downrange pixels by taking all the I and Q values from points d_0 to d_n and summing them in slow time. After the creation of the first row of pixels, the first row of I and Q values from point d_0 is removed, and the new row of information at point d_{n+1} is obtained. The Raspberry Pi then sums the bins in slow time again, now from point d_1 to d_{n+1}, this generates the second row of downrange pixels. This process of dropping the oldest piece of data and accumulating the newest one is repeated until the full image is formed [2].

The cross-range and downrange can be calculated for the radar using (2.4) and (2.5) [1] where downrange resolution relies on the RF frequency and cross-range resolution on the centre wavelength and three dB beamwidth.

$$\Delta R = \frac{c}{2B_r} \tag{2.4}$$

$$\Delta CR \geq \frac{\lambda_c}{2\theta_{3dB}} \tag{2.5}$$

Using the Demorad's given values for 3dB beamwidth and frequencies [5] the radar can achieve a down-range resolution of 43cm and a cross-range resolution of 0.5 cm. As a result, the produced image will have a fine resolution in cross-range but will smear in down-range. This as well lets the designers know how the test environment should be placed in downrange as well as if the Demorad is able to take multiple readings within each horizontal movement.

Interfacing

Raspberry Pi to Demorad

The Raspberry Pi will be interfaced with the Demorad through the USB to Micro USB ports found on both devices. This will allow for the seamless and quick transferring of data from one to another. The Raspberry Pi will be running the Python script which enables the discussion with the Demorad in order to obtain the values. The Demorad documentation and setup comes with predeveloped interfacing of a Demorad to a Raspberry Pi to allow for easier interfacing for the user and allow for the Raspberry Pi to obtain the data needed to form an image.

Battery to Demorad

The Demorad will be connected to an external battery supply mounted on the platform to provide power. Along with the Demorad's power requirements, the battery will be supplying the necessary 12V/3A [5]. This will be connected through a 12V male to male cable between the battery and the Demorad.

2.5 Display

Description

The purpose of the display is to present the final formed image that has been created by the platform. This is sent back to the external laptop to demonstrate that the platform is able to generate an image as well as present it to for a user from a safe environment. This helps demonstrate the scenario and concept of SAR as a useful surveillance tool.

Theory

The only considerations needed to be made for the display is the size of the image. Due to the fact that the platform is only traveling at most several meters means that the image is going to be much smaller than the screen. Due to the small size of the image, the screen size was not a dominant factor when using the laptop so long as the laptop was able to establish a Bluetooth connection to the Raspberry Pi.

Interfacing

The Raspberry Pi and external laptop will already share a connection from the laptop's ability to initiate the imaging sequence. This same connection between the Raspberry Pi and laptop will be used in order to send the image over Bluetooth from the Raspberry Pi to the laptop. Through the laptop's and Raspberry Pi's Bluetooth connection, the image will be transferred in file format to the laptop and subsequently opened.

3 Equipment Identification

Table 3.1 – Hardware Equipment

Part Description	Model Number	Expected Delivery
1.5'x2' Plywood	N/A	Received
Breadboard	N/A	Received
9V Battery	N/A	N/A
Raspberry Pi 5V Type C Power Cable	N/A	Received
DEMORAD 12V Power Cable	N/A	Received
4x Stepper Motor Mounting Brackets	N/A	Received
24x Female-Female Dupont Cables	N/A	Received
Razor Blade Stealth 13" Laptop	N/A	Received
5x Simulated Enemy Model Units (Action Figures)	N/A	N/A
Raspberry Pi 4 4GB Starter Kit	PI4-4GB-STR32F-C4-BLK	Received
4x Kuman Stepper Motors	28BYJ-48 ULN2003	Received
EVAL-DEMORAD	EV-DEMORAD24G	Received
TalentCell Rechargeable 12V/5V 6000mAh	YB1206000-USB	28 Nov 19
Compact Rechargeable Battery for Raspberry Pi - 10400mAh	N/A	28 Nov 19
70mm Aluminum Wheel – 6mm Bore	RB-GtF-16	28 Nov 19
USB-C to USB-C Charging Cable	AK-A8183011	28 Nov 19

Table 3.2 Software Equipment

Part Description	Model Number	Expected Delivery
Raspbian OS	N/A	Received
Thonny IDE	N/A	Received
PyCharm Python IDE	N/A	Received

The platform will be constructed with lumber, brackets, breadboard, and 9V batteries provided by the RMC tech shop with ordered wheels in order to construct a standing motorized platform. Sitting atop the platform will sit the Raspberry Pi, Demorad radar, Hyper Pixel display, and Demorad/Raspberry Pi battery pack with necessary connections in place. The Raspberry Pi will have all the necessary operating systems and Python libraries/IDEs installed.

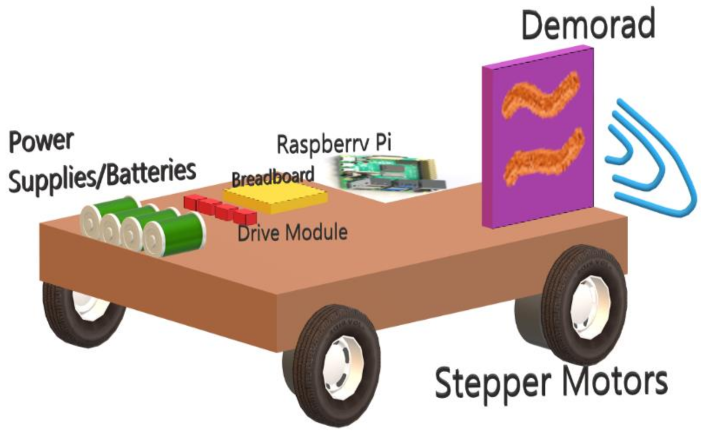
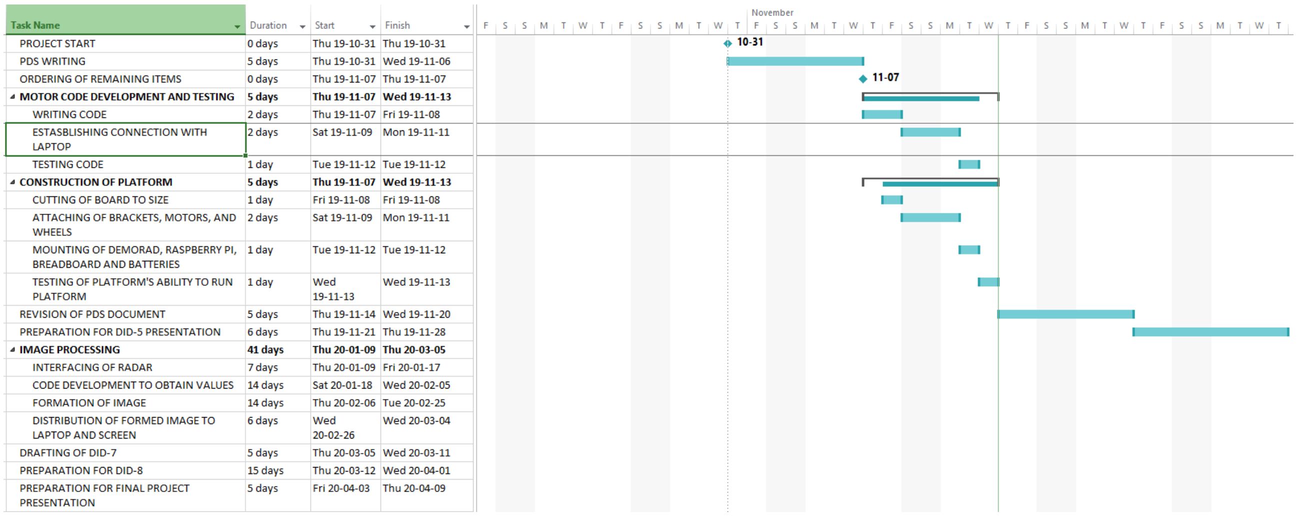


Figure 4 – Crude Layout of Design

4 Scheduling



Task Name	Duration	Start	Finish
PROJECT START	0 days	Thu 19-10-31	Thu 19-10-31
PDS WRITING	5 days	Thu 19-10-31	Wed 19-11-06
ORDERING OF REMAINING ITEMS	0 days	Thu 19-11-07	Thu 19-11-07
MOTOR CODE DEVELOPMENT AND TESTING	**5 days**	**Thu 19-11-07**	**Wed 19-11-13**
WRITING CODE	2 days	Thu 19-11-07	Fri 19-11-08
ESTASBLISHING CONNECTION WITH LAPTOP	2 days	Sat 19-11-09	Mon 19-11-11
TESTING CODE	1 day	Tue 19-11-12	Tue 19-11-12
CONSTRUCTION OF PLATFORM	**5 days**	**Thu 19-11-07**	**Wed 19-11-13**
CUTTING OF BOARD TO SIZE	1 day	Fri 19-11-08	Fri 19-11-08
ATTACHING OF BRACKETS, MOTORS, AND WHEELS	2 days	Sat 19-11-09	Mon 19-11-11
MOUNTING OF DEMORAD, RASPBERRY PI, BREADBOARD AND BATTERIES	1 day	Tue 19-11-12	Tue 19-11-12
TESTING OF PLATFORM'S ABILITY TO RUN PLATFORM	1 day	Wed 19-11-13	Wed 19-11-13
REVISION OF PDS DOCUMENT	5 days	Thu 19-11-14	Wed 19-11-20
PREPARATION FOR DID-5 PRESENTATION	6 days	Thu 19-11-21	Thu 19-11-28
IMAGE PROCESSING	**41 days**	**Thu 20-01-09**	**Thu 20-03-05**
INTERFACING OF RADAR	7 days	Thu 20-01-09	Fri 20-01-17
CODE DEVELOPMENT TO OBTAIN VALUES	14 days	Sat 20-01-18	Wed 20-02-05
FORMATION OF IMAGE	14 days	Thu 20-02-06	Tue 20-02-25
DISTRIBUTION OF FORMED IMAGE TO LAPTOP AND SCREEN	6 days	Wed 20-02-26	Wed 20-03-04
DRAFTING OF DID-7	5 days	Thu 20-03-05	Wed 20-03-11
PREPARATION FOR DID-8	15 days	Thu 20-03-12	Wed 20-04-01
PREPARATION FOR FINAL PROJECT PRESENTATION	5 days	Fri 20-04-03	Thu 20-04-09

Figure 5 – Scheduling of Project

The scheduling for the project is broken down into three main components, the creation of code in order to run the motors, followed by the construction of the system platform, and finally the formation of the image/distribution of the image. The creation of the motor code and the platform construction are slated to be finished before the Winter break and are simple to produce a moving platform with all the ordered parts in place. Sources online for stepper motors and the RMC tech shop ensure that these steps can be finished before the break and will progress swiftly. The SAR imaging algorithm requires more time in order to learn and properly debug, which will consume the bulk of the remaining time along with preparing all paperwork and presentations.

5 Unresolved Issues and Risks

The most pressing risk to the SAR imaging project is if the Demorad radar is not coherent between chirps. If the radar does not do this the SAR imaging algorithm will not work and the images will not be accurately produced. Therefore, in order to determine if this is an issue the radar must be set up so that the I and Q values are able to be read for a stationary reflective target and the phasor must be measured. If the phasor does not remain constant in between the measurements, then coherent integration is not being used and the major changes to the project will have to be done. After speaking with the supervisor, the solution is the introduction of a small target that is always in front of the radar and close to it. With this target in place and knowing the values that it returns the change in phase will be able to be determined and corrected for in the rest of the rows. This is the biggest challenge and must be overcome for the SAR imaging project to proceed.

Another risk is if the position data is not accurate enough in order to take the half-wavelength measurements. If this is the case more solutions will be examined in order to mitigate the problem. The first solution is to purchase rotary encoders that measure the rotational distance of the motors. That will provide a position to us instead of measuring a single step and will allow us to design a control system if the platform is unable to move in just a single axis. The second solution is to take more accurate measurements of how far one step of the motors moves the platform and to adjust the platform based on these calculations.

6 Calculations

Wheel Radius/Minimum Horizontal Displacement

```
c  = 3e8;
f = 24e9;
lambda = c/f;
d = lambda/2
theta = deg2rad(5.625);
r = d / theta
```

```
d = 0.0063
r = 0.0637
```

Downrange Resolution

```
c = 3e8;
fH = 24.3e9;
fL = 23.95e9;
Br = fH - fL;
deltaR = c/(2*Br)
```

```
deltaR = 0.4286
```

Crossrange Resolution

```
fH = 24.3e9;
fL = 23.95e9;
fc = (fH+fL)/2;
c = 3e8;
lambda_c = c/fc;
theta_3dB = deg2rad(76.5);


CR = lambda_c/(2*theta_3dB)
```

```
CR = 0.0047
```

7 Conclusion

The purpose of the preliminary design specification (PDS) was to provide more technical and informative insight into the SAR imaging project. Where the statement of requirements (SOR) simply stated the needs and large-scale components of the project, the PDS provided a deeper look into how each facet of the SOR was to link together and formed the overall project. This document also touched on the prior knowledge needed in order to construct a self-moving platform capable of producing a quality SAR image. Along with the discussion on the design of the project this document gave a detailed list of all required components and a timeline of the completion of the project. This document took previously stated requirements and gave the contextual specifications within the project and timeline for the designers to follow.

References

[1]M. A. Richards, J. Scheer, and W. A. Holm, *Principles of Modern Radar*. Raleigh, NC: Tes Dee Publishing Pvt. Ltd., (Published by arrangement), 2012.

[2]M. A. Richards, *Fundamentals of radar signal processing*. New York: McGraw-Hill Education, 2014. M. A. Richards, *Fundamentals of radar signal processing*. New York: McGraw-Hill Education, 2014.

[3]Dr. Joey Bray. "Block 7 Grating Lobes and 2D Arrays" course notes, EEE474.

[4]"Universal Wave Equation," *Wave Properties*. [Online]. Available: https://thepropertiesofwaves.weebly.com/universal-wave-equation.html. [Accessed: 06-Nov-2019].

[5]"EVAL-DEMORAD," *EVAL-DEMORAD Evaluation Board | Analog Devices*. [Online]. Available: https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/eval-demorad.html#eb-overview. [Accessed: 06-Nov-2019].

[6]"Kuman Stepper Motor for Arduino 5 sets 28BYJ-48 ULN2003 5V Stepper Motor ULN2003 Driver Board Dupont 40pin Male to Female Jumper Ribbon Cable K67," *www.kumantech.com*. [Online]. Available: http://www.kumantech.com/kuman-stepper-motor-for-arduino-5-sets-28byj-48-uln2003-5v-stepper-motor-uln2003-driver-board-dupont-40pin-male-to-female-jumper-ribbon-cable-k67_p0057.html. [Accessed: 06-Nov-2019].

[7]"Arc Length," *Arc Length definition - Math Open Reference*. [Online]. Available: https://www.mathopenref.com/arclength.html. [Accessed: 06-Nov-2019].

[8]"FAQs," *FAQs - Raspberry Pi Documentation*. [Online]. Available: https://www.raspberrypi.org/documentation/faqs/. [Accessed: 16-Nov-2019].

[9]G. W. Stimson, *Introduction to airborne radar*, 3rd ed. Raleigh, NC: SciTech Publishing, Inc., 2014.